Interpretation of inspection data emanating from equipment condition monitoring tools: Method and software

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Abstract

The presentation focuses on current industry-driven research that blends together risk estimation, using PHM, along with economic considerations to establish optimal condition-based maintenance decisions. Recent results of the research program are described including development of the EXAKT software, and its successful application to the interpretation of inspection data emanating from vibration monitoring in the food processing industry, oil analysis in an open pit mine, and seal failure data in a nuclear generating station.

1. Introduction

Cox (1964) in the section “10.4 Dependence of failures on wear” introduced the idea of deciding on the replacement time of an item based not only on its age, but also on its physical properties. Later Cox (1972) introduced the proportional hazard approach to estimating the risk of failure of an item, taking into account concomitant information. The work reported in our paper is a direct outcome of Cox’s insight that PHM can be applied in the reliability field. In particular we demonstrate its power in assisting reliability and maintenance professionals to intelligently interpret signals they obtain when using condition monitoring, where the objective is to obtain the maximum useful life, along with economic considerations, from each physical asset before taking it out of service for preventive maintenance.

Much research and product development in the area of condition based maintenance focuses on data acquisition and signal processing. The work reported in this paper addresses the third and final step in the CBM process – optimizing the decision making step.

Unquestionably, CBM is very successful in reducing the number of failures in a plant – but as Christer (1999) has stated, “seemingly CBM can be at the same time very effective, and rather inefficient”. The goal of CBM optimization is to achieve the right balance between risk and economics. Makis and Jardine (1992) developed a theory rooted in stochastic dynamic programming to optimize the risk and economic trade-off. This approach is illustrated in Figure 1 where it is assumed that as the equipment ages there is an increasing risk associated with an item failing in the next moment in time. The reliability specialist can select a risk cut-off level at which to intervene and replace the deteriorating equipment. Each possible risk level has an associated expected cost made up of the cost of preventive replacement and the cost consequence of an equipment failure. The key is to identify the optimal risk level at which the equipment should be replaced. Thus the plan is to monitor risk, using a PHM, and once the risk hits a specified value, then it is optimal to perform a preventive replacement. Of course, if the equipment fails it has to be replaced under failure conditions.

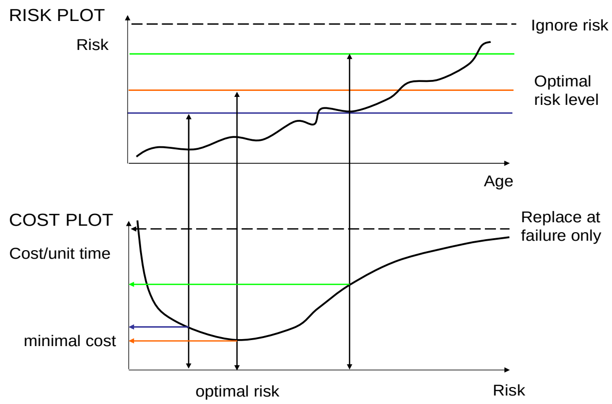

Figure 1: Risk Level and Optimal Policy

2. Managing Risk: A CBM Optimization Tool

Subsequent to the Makis/Jardine (1992) paper a research group was formed to take the theory and make it work in practice. To achieve this goal a number of companies supported in 1995 the creation of the Condition-Based Maintenance Consortium at the University of Toronto (CBM Lab) (www.mie.utoronto.ca/cbm). As a consequence, the EXAKT software (Banjevic et al 2001) was developed, along with addressing challenging theoretical issues that resulted from close collaboration with the consortium members (numbering 10 in 2004). There are two main components to EXAKT:

1. A risk calculation based on a Weibull PHM and Markov transition probability model for covariates.
2. A cost component that takes into account the cost per unit time associated with both a preventive replacement and a failure replacement.

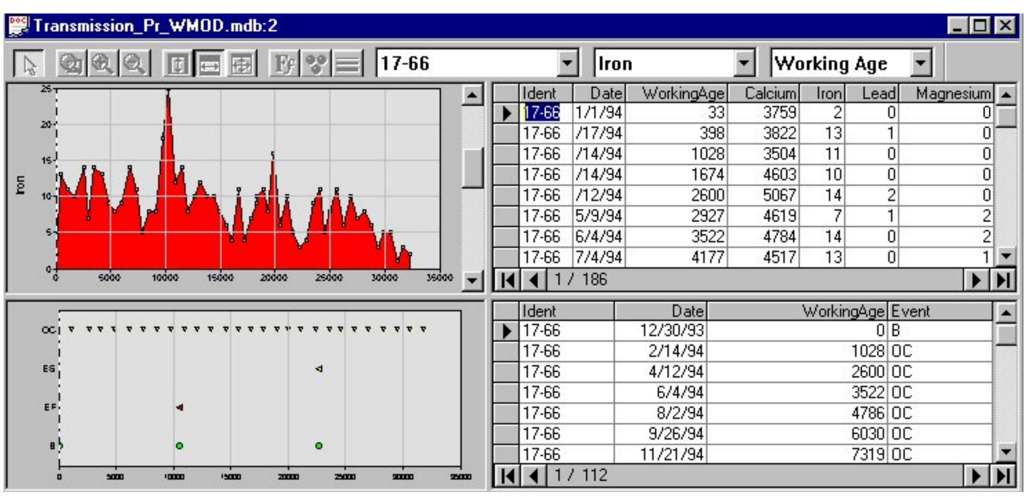

Figure 2: Inspections Records and Events Data

Figure 2 is a screen shot of condition monitoring data that is obtained from an equipment that is monitored through oil analysis and event data that provides information about the timing of equipment installations, removals (whether preventive and so treated as a suspension time, or due to failure) and any maintenance action, such as oil changes, that is recorded. Both types of data are then used to build the PHM. Combining the inspection records and the event data (Figure 2) enables the following Weibull PHM to be obtained:

$$h(t) = \frac{5.007}{38{,}988}\left(\frac{t}{38{,}988}\right)^{4.007} e^{0.2626\times Iron + 1.0522\times Lead}.$$

Incorporating cost data then enables the optimal decision chart to be obtained from the PHM, as illustrated in Figure 3.

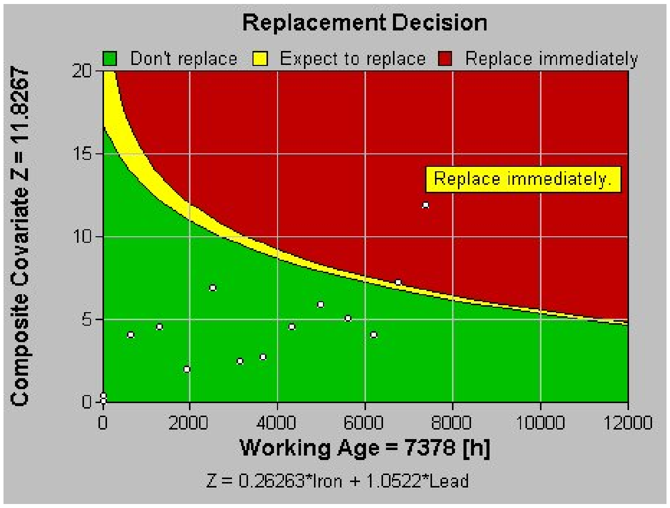

Figure 3: Optimal Decision Chart

Further details on the theory and its application to the CBM optimization work can be found in Banjevic et al (2001), and Vlok et al (2002).

3. Case Study Papers

Readers interested in further applications of the CBM optimization work can find details about pilot studies undertaken in the food processing industry in Jardine et al (1999), open pit mining in Jardine et al (2001) and in nuclear power generation, Jardine et al (2003).

4. Future research plans

Some of the research topics that are in future plans, or are already in development in the CBM Lab are: relaxation of a common assumption in the literature that at the maintenance intervention the item is returned to the statistically as good-as-new condition, inclusion of the cost of the condition monitoring in the decision optimization model and planning of the next inspection, calculation of the remaining useful life (Banjevic and Jardine 2004), and modeling of complex repairable systems (Lugtigheid et al

2004). Also, a collaborative project with IMS Centre at the University of Wisconsin-Milwaukee to create an integrated platform for CBM is currently underway (Lee et al 2004).

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